ELECTROMYOGRAPHIC STUDIES ON CROSSED ANASTOMOSIS BETWEEN THE TIBIAL AND THE FIBULAR NERVE IN DOGS

by

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INTRODUCTION

In relation to the problem whether permanent functional disturbances are left or not after cutting two functionally different nerves and suturing them crosswise, since LETIEVANT in 1873, RAWA, GUNN, SICK and SANGER, MENASSE, KENNEDY, OSBORNE and KILVINGTON, SHIBUYA, NORIOKA, BARRON, SPERRY and so on have reported on the results of the suture between heteronymous or heterogenous nerves, both in human beings and animals. There has not yet been, however, any unanimous opinion about the recovery of normal function after operation. The views presented so far can be divided into the following three.

1) A school which admits the satisfactory functional recovery occurring rather early in the postoperative period (RAWA, KENNEDY, OSBORNE and KILVINGTON, NORIOKA, BARRON and ARIZAWA).

2) Opinion of non-functional recovery (SPERRY and WATANABE).

3) Opinion by which the satisfactory recovery can take place only by the repeated exercises after the nerve regeneration (SPERRY).

ARIZAWA, a former member of our laboratory, in 1952, using 33 rabbits and 3 dogs, practiced the crossed anastomosis of the tibial with the fibular nerve and observed the restoration of normal functions within 6 months. He considered it as being the result of the functional compensation by the cerebrum and the spinal cord.

In 1954, ISHII in our laboratory, carrying out the crossed anastomosis between a spinal and the vagal nerve in the cervical region in cats, reported that the nerve regeneration was surely recognized by either histological study or by electrical stimulation, but the function regained was not normal.

In 1955, WATANABE, another member of our laboratory, practiced the crossed anastomosis between the tibial and the fibular nerve at the upper level of the thigh in dogs, and found the postoperative functional changes to be divided into three stadiums. In 3～6 months after operation the walk of the animals became seemingly normal, but after 6 months they walked abnormally again, and no restoration took place by the end of 12th postoperative month when they were killed.

Because his observations, however, were gross and clinical, the detailed physiological mechanism going on during the recovery was almost unknown.

In 1947, GOLSETH and FIZZELL, performing the suture immediately after cutting sciatic nerve in cats, observed the electromyogram with the progress of restoration. And he proved that the electromyographic restoration and functional recovery occurred hand in hand.

In 1952, KATO obtained the similar results, after the sciatic nerve suture in rabbits.

In the present report, I studied electromyographically the regenerative process of crossed nerve anastomosis and also the recovery of reflexes.

MATERIALS AND METHODS OF EXPERIMENTS

(1) Experimental Animals

Twenty-two adult dogs of about 10 kg body weight. Completely crossed anastomosis in 19 dogs and partially crossed anastomosis in 3.

(2) Experimental Equipments

The electrode used for E. M. G. was a coaxial needle made from a subcutaneous injection needle of 1/4 mm in diameter in which an enamel insulated cupreous wire of 100μ diameter was enclosed and fixed.

The electromyographic apparatus were the E. M. G. 52-5 type manufactured by Tokyo Denki-Seiki & Co. Ltd., with the frequency characteristics adjusted and the 2-beam E. M. G. apparatus by Sanei-Sokuki & Co. Ltd. In order to reduce induced alternating current at the time of observation of E. M. G., a pedestal, on which a dog was placed, was made, with insulators attached under its legs.

(3) Methods of Experiments

A) Surgical Operations

a) Narcosis: After the basal narcosis with 4% narcopon scopolamine, the intraperitoneal injection of 10% isomytal sodium solution 0.3cc pro kg was done. The operations were carried out under this isomytal general anesthesia.

b) Completely crossed anastomosis of tibial and fibular nerves: A skin incision of about 5 cm length was delivered on the posterior surface of the right upper thigh. Between M. biceps femoris and M. semitendineus, we could easily find the bifurcation of the sciatic nerve into the tibial and the fibular nerve. The both nerves, after fully separated from the surroundings, were cut at the point about 4 cm peripheral from the bifurcation, and the central end of the fibular nerve and the peripheral end of the tibial nerve were sutured with each other, and simultaneously the central end of the tibial nerve and the peripheral end of the fibular nerve were also sutured. The nerve suture was done following the method of TAKETOMO and WATANABE; the arterial tube preserved in 70% alcohol, was used for the intubation of the united nerve ends, and no suturing gut was passed through the nerve ends (Fig. 1a).

c) Partially crossed anastomosis: In the same way as in the completely crossed anastomosis, the both nerves were exposed. And they were slivered respectively in half. Each half of them was cut and the central end of the one was sutured with the peripheral end of the other (Fig. 1. b).

d) Unilateral decortication of motor areas: In the three dogs, which survived for more than one year and 4 months after the completely crossed anastomosis

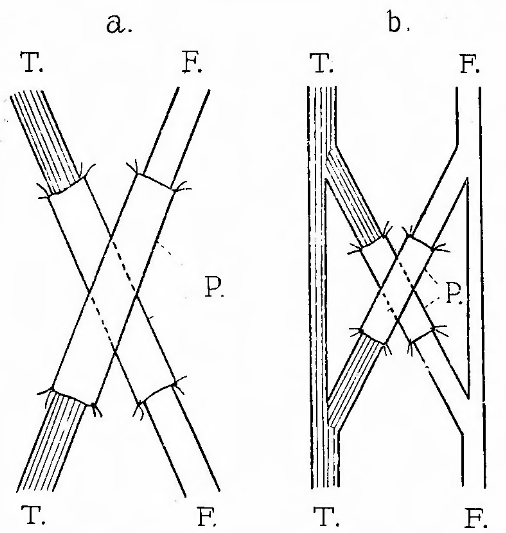

Fig. 1 Schematical illustration of crossed nerve anastomosis. (From WATANABE, Arch. Jap. Chir. **24**, 135, 1955)
a : Completely crossed anastomosis
b : Partially crossed anastomosis
T: N. tibialis
F: N. fibularis p : Arterial tube

and of which the functional recovery was satisfactory, I performed the unilateral decortication of the contralateral motor areas. As controls, the similar operation was carried out in 3 healthy adult dogs. The motor areas of dogs are considered to be situated in Gyri sigmoideus anterior et posterior and Gyri proreus and coronalis. By the left frontoparietal craniotomy the left frontal and the parietal lobe were fully exposed. By giving them electric stimulations of 60∾, 10 v, and obtaining the motor responses, I confirmed the motor areas and decorticated them widely enough.

B) Postoperative Neurological Changes (Clinical Symptoms)

1) Standing posture. 2) Walking, particularly crippling. The test was made not only in slowly walking but in rapid running. 3) Prompt and unprepared action ; the stepping of hungry dogs when they hurry up to approach the feed, or the postures of the right hindleg and foot when dogs spring up to the feed above the head. 4) Trophic disturbances : shedding of the hair, deformity of nail, hemorrhage and ulcer formation are often seen on the dorsal surface of the right foot. And the atrophy of crural and plantar muscles is also found.

C) Electromyogram

On the insulated pedestal above mentioned, a dog was placed and the three extremities except the right lower were fixed. Inserting an electrode into a muscle with no anesthesia, I observed E. M. G. by means of oscilloscope with Brown tube and took photographs if necessary. The examined muscles were M. tibialis anterior, M. gastorocnemius and M. plantaris. The time intervals of the E. M. G. examinations were 1∼10 days at the biginning, 20 days after 100 days and 30 days after 180 days. The dogs in which the E. M. G. study was made, were 19 in the group of completely crossed anastomosis. Among them, 6 survived for more than one year, the maximum survival being for one year and 6 months. Also the E. M. G. study was performed in 3 dogs with partially crossed anastomosis. The maximum survival was for one year and 4 months.

D) Reflex

1) Flexion reflex. In dogs, when the gluteal region or the lateral surface of the thigh is stimulated, the contraction of the anterior tibial muscle with the dorsal flexion of the foot occurs on the same side. At the time of this flexion reflex, the reflex waves in the E. M. G. of the anterior tibial muscle or the gastrocnemius in cases of crossed anastomosis were observed.

2) Achilles tendon reflex. Inserting an electrode into the gastrocnemius and also in the anterior tibial muscle in cases of crossed anastomosis, I observed the reflex wave in the E. M. G. which was elicited by the knock on Achilles tendon.

E) Anatomical and Histological Researches

After the animals were slaughtered, their cerebrum (decorticated), the nerves at the sites of crossed anastomosis and the muscles under their innervation were observed with the naked eyes. And the nerves at the site of crossed anastomosis were subjected to the histological examination after the transverse section and Weigertstaining. The muscles were stained by hematoxylin-eosin.

RESULTS OF EXPERIMENTS

1) Postoperative Neurological Symptoms

a) Completely crossed anastomosis (Fig. 2) : The first stadium : Immediately after the operation, the right foot became entirely immobile and flaccid. At the standing position the toes were plantarly flexed though the ankle joint held the almost normal position. The dogs walked with the right foot dragging. On running or going downstairs, they mostly use the remaining three feet. In this stadium, the complete algesia of the leg and foot was seen and the dogs did not react to the needle piearcing. The muscles of the right leg and foot gradually atrophied and became impalpable. The shedding of the hair was distinctly observed and in about half cases the ulcer formation was found on the back of the foot. At the beginning the ulcer was dry and not much hemorrhagic. After 2 or 3 months, however, the tendency to bleeding appeared and the ulcer gradually healed.

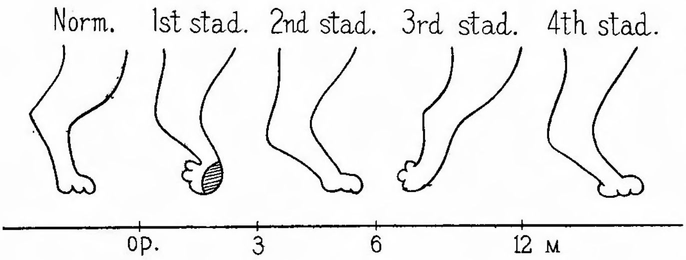

Fig. 2 Schematical ilustration of the postoperative state of the hind leg on the side of the operation.

If the dogs were frequently compelled to walk in this stadium, the ulcer was markedly enlarged, the nails and the digital ends were deformed or the tendons were exposed in the ulcer and wasted.

The second stadium : After 80 days or 90 days at the latest, the muscle tonus of the leg was gradually regained. The dogs now entered into the second stadium. At the standing posture, the toes were sometimes plantarly flexed but mostly took the normal position. The ankle joint had the trend to sink. The dogs walked almost normally, and never dragged their right foot, though the movement of the foot was somewhat slow.

At the beginning of this stadium the pain sensation was distinctly regained in the leg, but its recovery in the planta was delayed for one or two more months. The muscle of the right leg became palpable and nearly normal in thickness. The epilation was restored and the ulcer healed in almost all the cases.

The third stadium: After 6 months the muscle tonus in the plantar region returned, and at the standing posture the ankle joint and the toes were plantarly flexed in most cases. The walk was rather alike that in the first stadium. The dogs walked, stretching their right posterior extremity with the toes flexed plantarly. At the time of a prompt and unprepared action the reversed movement took place. On springing up to the feed, the dogs fell down to the right side, taking a false step with the right leg.

The fourth stadium: After about one year, the plantar flexion of the toes became less and less marked and the ankle joint stood mostly rather lower. The walk became more skillful in most cases. The reversed movements rarely occurred. On springing up to the feed, most of the dogs never fell down. These restorations went on very slowly and there were individual differences among the dogs. Of the six dogs, surviving for more than one year after operation, one showed no recovery, 2 slight restoration and 3 marked restoration. Even the best restored 3 dogs, sometimes, flexed their toes plantarly, and their movement of the right posterior extremity was slightly slow at walk. But the reversed movement was only rarely seen and they could spring up correctly to the feed.

The above mentioned four stadiums can be shown in a scheme (Fig. 2).

b) Functional disturbances after unilateral decortication of motor areas:

In control dogs, the motor hemiparalysis was observed on the contralateral side. The anterior and posterior extremities on the paralized side were flexed and the head deviated to the paralized side. The trunk was bent with concavity toward the paralized side. On standing they were unstable and apt to fall down to the paralized side. At walk they moved round, discribing a circle around the paralized side. These symptoms gradually improved and returned to normal usually in about 2 or 3 weeks. But somewhat different was the result in the 3 dogs, which had undergone crossed anastomosis of peripheral nerves more than one year and 4 months previously with good postoperative functional restoration and then underwent additional contralateral decortication of motor areas. Although the disturbances in standing and walking were recovered in 2 or 3 weeks in these cases, they were apt to stretch their right posterior extremity at the ankle joint at the time of taking feed or of running away, and accordingly sometimes fell down. In other words, thry showed the distinctly reversed movement in such actions. To spring up to the feed was impossible. This phenomenon persisted for one month and 15 days after the decortication of motor areas.

c) Partially crossed anastomosis: No motor disturbance was observed at any time after the operation, even one year and 4 months later. In the standing posture, walking and prompt and unprepared action, no changes were demonstrated.

2) E. M. G.

a) Fibrillation voltage (Fig. 3): This is the spike discharge appearing spontaneously in individual muscle fibers when the nervous control is lost. Its amplitude is $10\sim100\mu$v, duration is $1\sim2$ msec., repetition frequency varies from 2 to 3 per sec. For 4 days after the crossed anastomosis the muscle was in electrical silence, and on the fifth day the fibrillation voltage appeared for the first time. At the beginning it appeared only in a few points in the muscle with

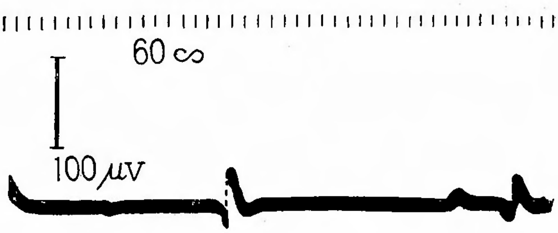

Fig. 3 Fibrillation voltage.

the amplitude less than 50μv, but on the 10th day after the operation it was demonstrated in almost all points in the muscle and its amplitude in all three muscles reached to 100μv at the maximum.

In the anterior tibial muscle on the 50th day after the operation fibrillation voltages diminished and were demonstrated only in a few points and on the 60th day they were almost undemonstrable except in some dogs (Fig. 7).

In some parts of the gastrocnemius they appeared on the 5th day, but began to diminish 10 days ealier than in the anterior tibial. Also in the plantar muscle they appeared on the 5th day, persisted for a long time and diminished on the 120th day.

b) Complex N. M. U. voltage (Fig. 4) : During the process of nerve regeneration, a polyphasic wave can be observed. Its amplitude is 200 ~ 600μv, duration is 5 ~ 15 msec. and repetition frequency varies from 2 to 30 per sec. WEDDELL, GOLSETH and FIZZEL, and KATO called this wave as the nascent motor unit voltage. On the 50th day after the operation this wave appeared in some parts of the gastrocnemius and then temporarily increased but afterwards gradually decreased. On the 120th day it could no more be demonstrated. In the anterior tibial muscle it was found on the 60th day and disappeared on the 120th day. In the plantar muscle it appeared on the 140th day and became undemonstrable on the 180th day (Fig. 7).

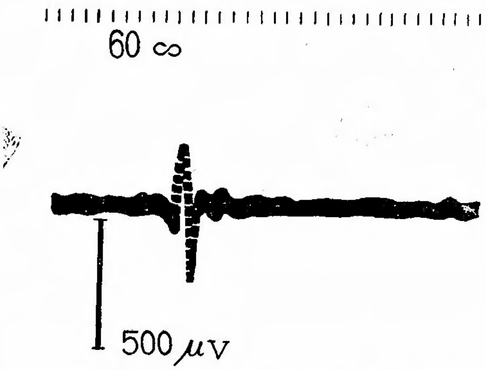

Fig. 4 Complex N. M. U. voltage.

c) Normal N. M. U voltage: In the E. M. G. of the normal neuromuscular system the waves are mostly diphasic or triphasic, with amplitude 500 ~ 2000μv, duration 5 ~ 10 msec. and repetition frequency varying from 5 to 30 per sec. On the 60th day the normal N. M. U. voltage was observed in both the anterior tibial and the gastrocnemius muscle (Fig. 7). And it gradually increased and on the 90th day it was demonstrated at almost all points in the muscles. In the plantar muscle its appearance was delayed and could first be demonstrated on the 160th day. Then it increased rapidly, though it was intermingled with more fibrillation voltages than in the crural muscles (Fig. 5).

d) Reinnervation voltage: YAHR, HERZ, MOLDAVER and GRUNDFEST noticed an extremely large wave appearing at the time of the voluntary contraction of muscles in the patients 3 ~ 5 years after the suture of a peripheral nerve. The wave

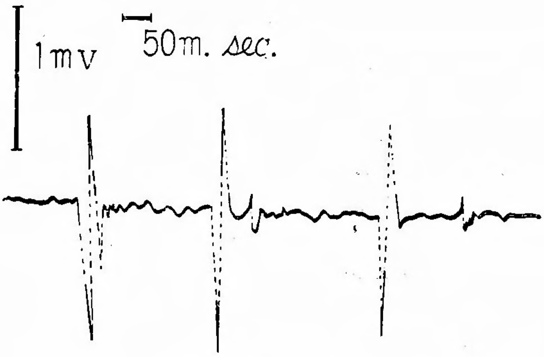

Fig. 5 Coexistence of normal N. M. U. voltage and complex N. M. U. voltage.

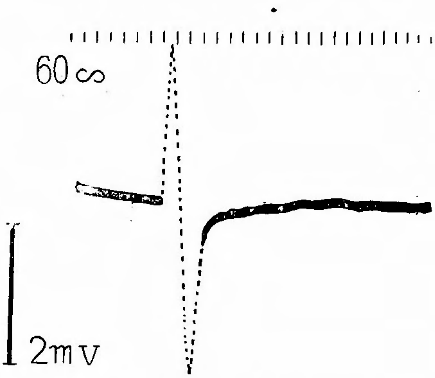

Fig. 6 Reinnervation voltage.

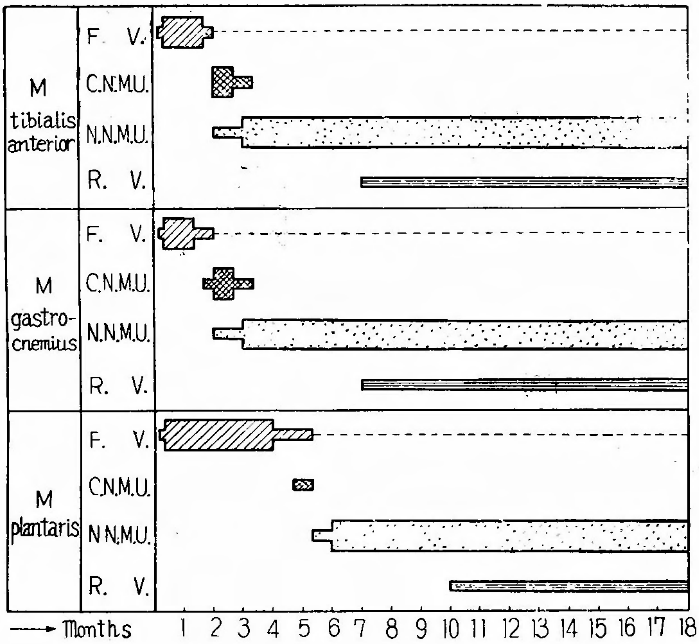

Fig. 7 E. M. G. after completely crossed anastomosis.

Definite decrease or increase in the E. M. G. patterns observed in this experiment, could not be expressed numerically and consequently in graphic form. And so, number of the intramuscular points of occurrence of fibrillation voltages, complex N. M. U. voltages, normal N. M. U. voltages and reinnervation voltages were expressed in the following way:

: many
: moderate
······ : few
F. V. ······ Fibrillation voltage
C. N. M. U. ······ Complex N. M. U. voltage
N. N. M. U. ······ Normal N. M. U. voltage
R. V. ······ Reinnervation voltage

(reinnervation voltage) is almost diphasic or triphasic, with amplitude 5～15mv., duration 5～10 msec. and repetition frequency reaching to 50 per sec. (Fig. 6). Seven months after the operation in cases of the present study the reinnervation voltage of 5～7 mv was found in the both crural muscles (Fig. 7). It was observed in almost all of the cases and persisted for a long time. Its appearance was less frequent in the anterior tibial muscle and more frequent in the gastrocnemius, particularly in its lower parts. In the plantar muscle the reinnervation voltage of about 4 mv appeared after 10 months. Its amplitude was somewhat smaller than that of the standard reinnervation voltage, probably due to the smoll size of the plantar muscle.

The results above mentioned are shown in Fig. 7.

In the E. M. G. of the dogs in which partially crossed anastomosis was carried out, the appearance and disappearance of unusual waves were similar in nature and in time of occurrence to those in the dogs with completely crossed anastomosis. But in the former animals, from the beginning, the normal N. M. U. voltage was mixed.

3) Time Relationship between Electromyographical and Functional Recovery (Fig. 8)

About the time when the anterior tibial and the gastrocnemius muscle, namely the crural muscles, were electromyographically normalized, the dogs entered

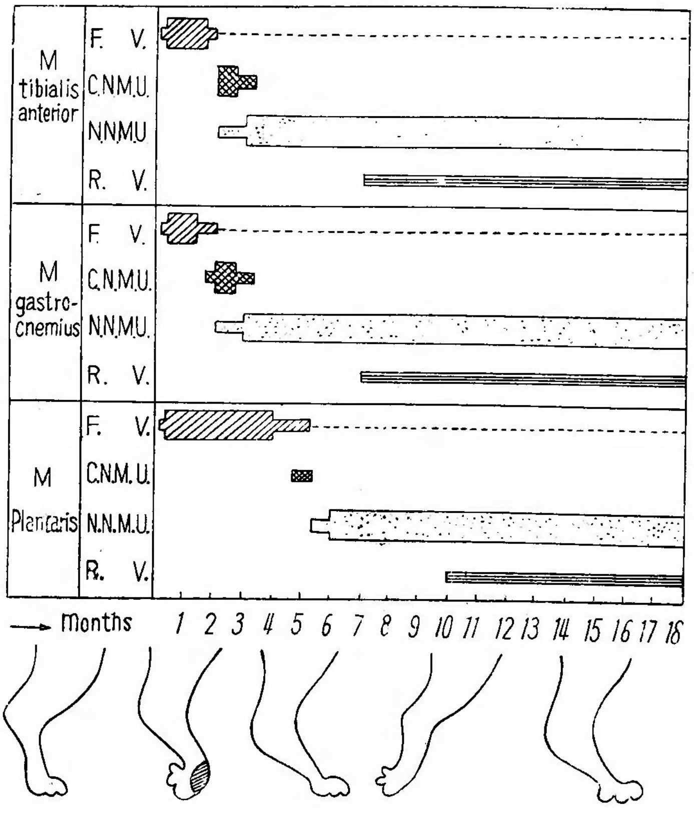

Fig. 8 Time relationship between the E. M. G. and the functional recovery.

neurologically the second stadium. And next, about the time when also the plantar muscle was electromyographically normalized, namely the three muscles were all normalized, the dogs entered neurologically the third stadium.

The reinnervation voltage was found in or after the third stadium, but its occurrence not only in the crural muscles but in the plantar muscle, was seen in or after the later period of the third stadium.

4) Reflex

a) Flexion reflex: Since the detailed investigation of SHERRINGTON, this reflex has been considered as a kind of protecting reflex, in which to a single stimulus a group of flexores reacts synergically. When pain fibers in the skin are stimulated, the most powerful flexion reflex occurs, but also at the stimulation of muscle afferents, e. g. from the sartorius or from the quadriceps femoris lateralis, a flexion reflex is elicited in the semitendineus (FULTON 1955). I found a flexion reflex in dogs, which is simple and quite easily praticable: By the tap on the gluteal region, the flexion occurs in the lower extremity on the same side and expecially markedly in the muscles of the dorsal flexor in the leg. This reflex was quite useful in the present study. Although in this reflex the dorsal flexion of foot was recognizable with the naked eyes, it could be demonstrated more exactly by the observation of a reflex wave in the electromyogram of the tibialis anterior. The wave was polyphasic with the amplitude 1~5mv (Fig. 9).

In and after the second stadium after crossed anastomosis, this reflex was always reversed. At the tap on the gluteal region, the dogs flexed their ipsilateral foot plantarly. In the observation of electromyogram, no spike could be found in the tibialis anterior, but a reflex wave was demonstrated in the gastrocnemius. This reversed reflex persisted even after more than one year and 6 months.

b) Achilles tendon reflex: It is generally known that, at the knock on Achilles

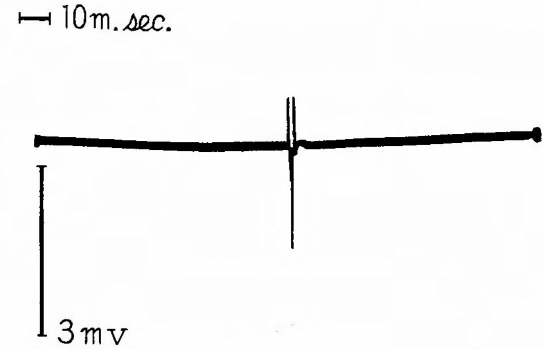

Fig. 9 Gluteal reflex.

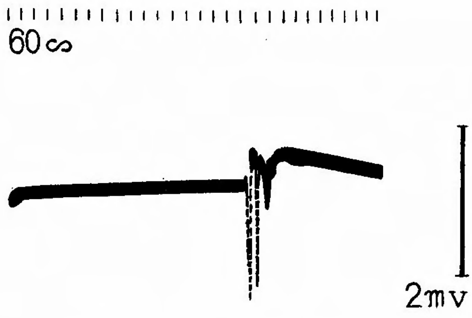

Fig. 10 Achilles tendon reflex.

tendon, the reflex contraction of the gastrocnemius occurs and the foot is plantarly flexed. This is demonstrable in dogs with the naked eyes. To demonstrate it more exactly, however, I observed the reflex with electromyograph and confirmed that the reflex in the dogs in or after the third stadium never became reversed but remained ordinary. In the E. M. G. a polyphasic reflex wave with the amplitude of 2~5 mv was recorded from the gastrocnemius (Fig. 10). At the knock on

Achilles tendon the E. M. G. with an electrode inserted into the tibialis anterior showed no spike. Because both the centripetal and centrifugal fibers, constituting this reflex arc, which normally run in the same nerve trunk (N. fibularis), degenerate and regenerate at the same time by crossed anastomosis, though regenerating fibers come from the proximal part of N. tibialis, there is no reason to cause the presisting disturbance of this reflex after the complete healing of the anastomosis. It is different from the gluteal flexion reflex above mentioned.

5) Anatomical and Histological Finding

a) Anatomical Finding: The site of crossed anastomosis in the dogs more than one year after the operation showed almost no, or slight if any, adhesion to the surroundings. The arterial tube used for the intubation of the union line, still remained as a membranelike tissue and the adhesion to the underlying nerve was loose. Any neuroma formation was not found. The peripheral part of crossed anastomosis reached almost to the same size as the central part. In all the crural and plantar muscles after more than one year, no muscular atrophy was found and their thickness was nearly the same as on the other side. Their colour was normal. In the cerebrum of the dogs in which the unilateral decortication of motor areas was done, Gyri sigmoideus posterior et anterior and Gyri proreus and coronalis proved to have really been removed entirely in all the cases.

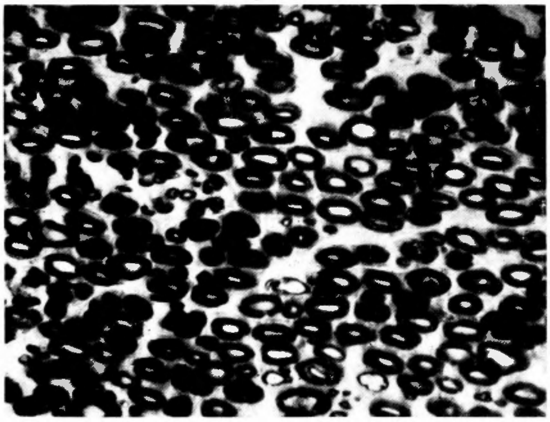

Fig. 11. Gross section of the healthy nerve. (Weigert's stain. ×600)

b) Histological Findings: In the peripheral part of crossed anastomosis the thickness of nerve fibers after 6 months was seen to be somewhat smaller in the transverse section, as

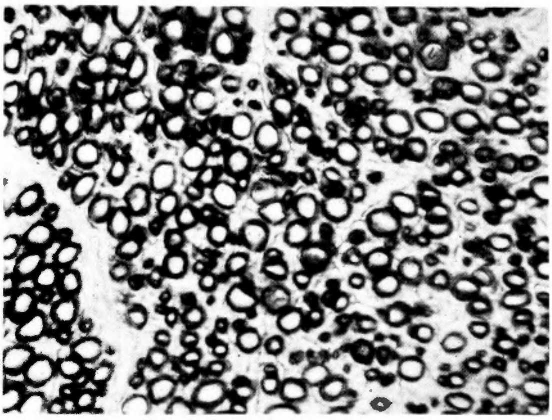

Fig. 12 Gross section of the nerve peripheral to anastomosis. 16 months after the operation.

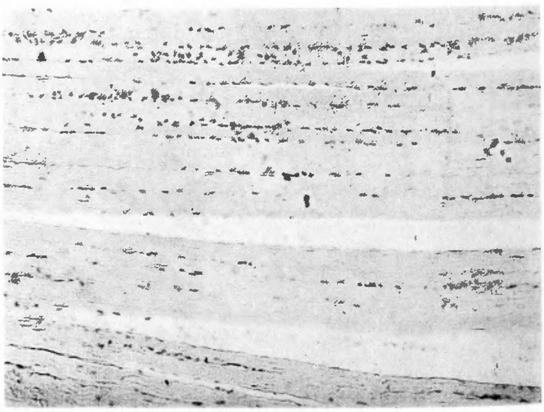

Fig. 13 Longitudinal section of the gastrocnemius muscle. 18 months after the operation. (hematoxylin-eosin stain. ×100)

compared with that in the central part. But after more than one year it was the same as that of the central part (Fig. 11. 12). And the number of fibers was also numerous enough.

The crural and plantar muscles more than one year after the operation were all normal and showed no sign of degeneration (Fig. 13). In some cases, the cellular infiltration was found in some regions, but the atrophy or irregular arrangement of muscular fibers was almost undemonstrable.

DISCUSSION

The course of the nervous regeneration after crossed anastomosis of peripheral nerves has been followed by means of the E. M. G. At a certain interval after the crossed anastomosis, I observed the E. M. G. of the peripheral muscles and noticed that the changes were not different from those after the non-crossed nerve suture. But in the crossed anastomosis between the tibial and the fibular nerve, contrary to the non-crossed suture, the regeneration of nerve fibers, and the reinnervation of muscles do not mean the restoration of the same function as that before the operation. They, however, do not always result in the reversed movement. The reason may be that, at first, the muscles under the innervation of the tibial and the fibular nerve are differently distant from the suture (for instance the crural and plantar muscles). At second, not only the motor fibers, but also the sensory fibers are crossed. At third, there may be the possibility of the functional adaptation in the central nervous system to the altered peripheral innervation. Various combinations of these factors may result in various disturbances after the crossed anastomosis.

As to the motility of the animals after the operation, the above mentioned 4 stadiums can be classified. The first stadium is no doubt the stage of paralysis caused by nerve cutting. The seemingly normal motility in the second stadium is considered to be due to the establishment of rough reinnervation. In this stadium the reinnervation seems to have taken place in the crural muscles, though not completely; but it does not in the plantar muscles. Since in this muscle the electric reaction of degeneration still persists and the analgesia of the plantar skin remains, the recovery of the deep sense necessary for the perfection of posture and walking is supposed to have not yet occurred. In this stage of incomplete recovery, when the plantar muscle cannot move but the crural muscles can do to a certain degree, the dogs seem to be able to walk almost normally.

The third stadium is the stage when the nerve reinnervation is completed down to the peripheral ends. The reflex in which the centripetal and centrifugal reflex arcs pass in the same nerve trunk, for instance stretch reflex, does not suffer any disturbance, even after the crossed anastomosis, if the nerve regeneration is sufficient. Therefore, the Achilles tendon reflex is normal. However, the posture of the ankle joint in the abnormal plantar flexion on standing and walking should be considered as a tonus unbalance of both the dorsal flexor and the plantar flexor muscle acting upon the ankle joint. On the other hand, the reversed movement takes place at the time when the motor impulse comes from the brain, for instance, at a prompt and unprepared action, or at the time of a reflex movement of the lower leg initiated from the sensory nerve, which is uninfluenced by the crossed anastomosis (such as the nerve in the gluteal region).

The fourth stadium had no great difference from the third, either in E. M. G. or in reflex movement. The fact that the standing and walking are nevertheless nearly normal, is suggestive of the functional compensation by the higher nervous center. Also the fact that the improvement of motility characteristic of the fourth stadium is lost after the decortication of left motor areas supports this assumption.

In 1947, SPERRY, performing crossed anastomosis of the nerves going to the extensor and the flexor of the ellbow joint in monkeys, restored the normal function after exercise for 3 years. In the present experiment, no special exercise was practiced. But the posterior extremties of dogs were always forced to perform some movement which was indispensable for the daily life. Thus, it can be easily guessed that the dogs must have fully exercised.

Judged from these facts, long time after the crossed anastomosis of peripheral nerves in dogs, the almost normal function can be restored probably due to the functional compensation by the cerebrum. Therefore, in man, whose cerebrum develops much more than that of dog, the possibility of cerebral compensation is considered to be for greater.

I should like to call the four postoperative stadiums of the present experiments as follows. The first is the stadium of paralysis, the second the stadium of seeming compensation, the third the stadium of reversed movement and the fourth the stadium of true compensation.

SUMMARY

Performing the completely and the partially crossed anastomosis between the tibial and the fibular nerve at the level of the right upper thigh of dogs, I studied the changes in the E. M. G. and reflexes (gluteal flexion reflex and Achilles tendon reflex) during the course of functional recovery after the operation for one year and 6 months at the longest.

1) The functional recovery after the completely crossed anastomosis goes on in four stadiums; the first stadium (1～3 months; the stadium of paralysis), the second (3～6 months; the stadium of seeming compensation), the third (6～12 months; the stadium of reversed movement) and the fourth (after 12 months the stadium of true compensation).

2) In the 3 dogs of which the two nerves were slivered in each half and anastomosed in partially crossed way, the motor or sensory disturbances were not noticed through one year and 4 months after the operation.

3) In the E. M. G. on the 5th day after the completely crossed anastomosis, the fibrillation voltage was seen in the muscles under control. In the crural muscles (the anterior tibial and the gastrocnemius) the complex N. M. U voltage (nascent

motor unit voltage) was found on the 50～100th day, and besides this, the normal motor unit voltage appeared concomitantly on the 60th day, increased gradually, and at last on the 90th day it was demonstrable at almost all points in the muscles. Thus, the electromygraphical restoration of the crural muscles was completed. In the plantar muscles, the same process was noticed but the time of their appearance was later and the satisfactory restoration took place on the 180th day.

4) The reinnervation voltage appeared on the 7th month after the completely crossed anastomosis in the crural muscles, and on the 10th month in the plantar muscles.

5) As to reflexes, the Achilles tendon reflex appeared normally in spite of the crossed anastomosis, but the flexion reflex elicited by the stimulus to the gluteal region on the same side appeared in reversed way and remained unchanged till the last. The reversed movement appearing at the time of a prompt and unprepared action lasted till the third stadium, but changed to the ordinary movement in the fourth stadium.

6) After the decortication of left motor areas in the 3 dogs, in which the completely crossed anastomosis had been done with good functional recovery one year and 4 months previously, the regression from the fouth stadium to the third was seen.

7) The success of the crossed anastomosis was confirmed by the postmortem macroscopic and microscopic examinations of the nerves and the muscles under innervation.

8) Judged from these results, the complete functional recovery is possible, if the sufficient period of time passes after the crossed anastomosis of peripheral nerves. It is supposed that the cerebral cortex participates in this compensatoy phenomenon.

REFERENCES

1) Araki, C.: Surgical Experience with Injuries of the Peripheral Nerves. Saishin Igaku., **2**, 9, 1947. 2) Arizawa, G.: Experimental Studies on the Crossed Anastomosis of Antagonistic Peripheral Nerves. J. Jap. Surg. Soc., **53**, 91, 1952. 3) Barron. D. H.: The Results of Peripheral Anastomosis between the Fore and Hind Limb Nerves of Albino Rats. J. Comp. Neurol., **59**,301, 1943. 4) Ballance, C.: A Case of Facial Palsy Treated by Faciohypoglossal Anastomosis in wh-ich an Anastomosis was made between the Spinal Accessory and the Distal segment of the Divided Hypoglossal Nerve. Lancet, **1**, 1675.1909.
5) Davidson, A.: Ueber die Nervenpfropfung im Gebiete des Nervus facialis. Bitr. z. klin. Chir., **55**, 472, 1907.
6) Denny-Brown, D., and Penngbacker, J. B.: Fibrillation and Fasciculation in Voluntary Muscle. Brain., **61**, 311, 1938. 7) Ishii, S.: Experimental Study on the Possibility of the Functional Restoration After anastomosis between a Spinal Nerve and the Vagal Nerve. Folia Psychiat Neurol. Jap., **8**, 69, 1954. 8) Ishii, S.: Histological Studies of the Anastomosis between a Spinal and Vagal Nerve. Folia Psychiat. Neurol. Jap., 8, 87, 1954. 9) Fulton, J. F.: Physiology of the Nervous System. Oxford. med. Publication. II. Edition, 91, 1947. 10) Golseth, J. G. & J. A. Fizzell: Electromyographic Studies on Cats after Section and Suture of the Sciatic Nerve. Amer. J. Physiol., **150**, 558, 1947. 11) Kato, T., Yasuda, I. & Maehara, S.: Electromyographic Study of the Nervous-regeneration., J. Jap. Orth. Surg. Soc., **26**, 319, 1952.
12) Kizawa, K.: Histological Review on the Regeneration of the Peripheral Nerves. Nisshin Igaku., **29**, 31 and 183, 1940. 13) Kirihara, S. and Y. Kobayashi: Experimental Study on Transplantation of the Peripheral Nerves. Brain

and Nerve, 2, 347, 1949. 14) Norioka, E.: Ueber die Nervennaht zwischen dem N. vagus und dem N. Phrenicus. Kyoto Daigaku Daisan Kaibogaku Rombunshu, 1, 4, 14, 1934.
15) Shibuya, K.: Eine Funktionumstimmung nach der totalen Kreuznaht zwischen dem N. peroneus und N. tibialis. Kyoto Daigaku Daisan Kaibogaku Rombunshu, 1, 4, 65, 1934.
16) Sick, C. und A. Sanger: Heilung einer in Folge traumatishen Defekts bedingten Lähmung des Radialis durch Vernähung des peripheren Endes dieses Nerven mit dem Medianus. Langenbecks Arch., 54, 271, 1897.
17) Sperry, R. W.: The Functional Results of Muscle Transposition in the Hind Limb of the Rat. J. Comp. Neuro., 73, 379, 1940.
18) Sperry, R. W.: The Effect of Crossing Nerves to Antagonistic Muscles in the Hind Limb of the Rat. J. Comp. Neurol., 75, 1, 1941.
19) Sperry, R. W.: Effect of Crossing Nerves to Antagonistic Limb Muscles in the Monkey. Arch, Neurol. Psychat., 58, 452, 1947
20) Starlinger, J.: Die Durchschneidung beider Pyramiden beim Hunde. Neurol. Centralbl., 14, 390, 1895. 21) Taketomo, T.: A New Method of Nerve Suture and of Repair of Nerve Defect. Kyoto Igakkai Zasshi, 2, 628, 1952.
22) Watanabe, K.: A New Method of Peripheral Nerve Anastomosis: Reunion of a Severed Nerve by Tubulation with an Arterial Tube Fixed and Preserved in 70% Alcohol. Arch. Jap. Chir., 23, 458, 1954. 23) Weiss, P.: Reunion of Stumps. of Small Nerves by Tubulation instead of Suture Sience., 93, 69, 1941. 24) Watanabe, K.: Experimental Study on Crossed Anastomosis between Antagonistic Peripheral Nerves. Arch. Jap. Chir., 24, 132, 1955. 25) Yahr. M. B., E. Herz., I. Moldaver &. H. Grundfest.: Electromyographic Patterns in Reinnervated Muscle. Arch. Neurol. Psychiat., 63, 728, 1950.

和文抄録

犬に於ける脛骨神経腓骨神経交叉縫合の筋電図学的研究

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犬22匹を用い，脛骨神経と腓骨神経を右大腿で完全交叉縫合及び半交叉縫合を行い，術後の機能状況に並行して筋電図及び反射（臀反射及びアキレス腱反射）を追求し最長1年6ヵ月に及んだ．

1) 完全交叉縫合では術後機能は第I期（1～3ヵ月．麻痺期）第II期（3～6ヵ月仮性代償期）第III期（6～12ヵ月逆運動期）第IV期（12ヵ月以後，真性代償期）に分ける事が出来る．

2) 半交叉縫合で1/2神経を交叉した3匹では術後1年4ヵ月を通じて運動，知覚の障害は見られなかつた．

3) 筋電図は術後5日目より支配下の筋肉にFibrillation voltage を認めるが，下腿筋では50日～100日の間に Complex N. M. U. voltage を認め，これと並行して60日以後には Normal N. M. U. Voltage が出現，次第に増加して90日では殆んど総ての部位に Normal N. M. U. Voltage を認めるに至る．即ち下腿筋の筋電図学的正常化が完成する．足蹠筋では同様の経過を取るが，その発現時期は遅れ180日で正常化する．

4) Reinnervation voltage が下腿筋で7ヵ月，足蹠筋では10ヵ月に出現する．

5) 反射はアキレス腱反射は交叉縫合にも拘らず正常通りに出現するが，同側腰部の刺戟による屈曲反射は最後迄反対に出現する．

6) 術後1年4ヵ月以上で機能恢復良好な3匹の左側運動領切除では明かに第IV期より第III期への逆行が観察される．

7) 縫合部神経及び支配筋肉の肉眼的及び組織学的所見より交叉縫合が成功している事を確めた．

8) これ等の事より末梢神経交叉縫合は相当の時間を経過すれば，正常機能恢復が可能なものであり，これには大脳皮質が関与するものと考えられる．